Analysis of Tui Chub Data Collected at Diamond Lake by the Oregon Department of Fish and Wildlife 1992-2003

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INTRODUCTION

Diamond Lake is located in the Cascade Mountains 76 miles east of Roseburg, Oregon. Diamond Lake is a natural lake that has a surface area of approximately 3,000 acres and a volume of 68,000 acre-feet. The lake has been stocked annually with rainbow trout (*Oncorhynchus mykiss*) since 1910. Stocking was highly successful and lead to Diamond Lake being considered a premier trout fishery in the state. In 1954, rotenone was used to eradicate tui chub (*Gila bicolor*) which had been introduced into Diamond Lake. The chub had become so numerous in the late 1940's and early 50's that they negatively impacted the food resources in the lake and subsequently reduced the production of trout. The chub eradication was successful, the fishery was restored, and angler trips grew to over 80,000 trips per year from 1963 through 1990 (Loomis et al. 1999).

After 38 years, chub were again documented in Diamond Lake in 1992 (Loomis et al. 1999). During the last decade while the chub population increased, food resources (particularly zooplankton) in Diamond Lake were again depleted (Eilers et al. 2001) and the growth rate of fingerling trout decreased (Loomis et al. 1999). Additionally, water quality has decreased in Diamond Lake and lake use restrictions have been established during a portion of each summer since 2001 due to toxicity from large blooms of *Anabaena sp.* phytoplankton. This increase in *Anabaena* may be linked to a change in zooplankton and phytoplankton interactions due to the dominance of tui chub in Diamond Lake (Eilers et al. 2001).

Efforts are underway to evaluate the status of Diamond Lake and to select a course of action for managing the lake. The purpose of this report is to help this evaluation by summarizing the tui chub data collected by the Oregon Department of Fish and Wildlife (ODFW) since 1992. The data was used to estimate the population of chub in Diamond Lake, plus look at reproduction, sex ratios and the size class distribution of chub. This data was also used to construct models to predict the population trend of the chub if no action was taken to control the chub population.

METHODS

Counts

Historically trap nets have been used to monitor the growth of fingerling rainbow trout released into Diamond Lake. The trap nets (Six Foot Oneida Lake Trap Net, Research S. Inc., Baffle, WA) have a main box that is approximately 7’ x 6’ x 6’ in size and have two 12’ x 6’ wings which flare from the main box at a 35-degree angle (Figure 1). Both the main trap box and the wings have an internal mesh fyke to capture fish. The trapnet mesh size is #112, 0.69 inch stretch nylon. The traps are set by tying a 100’ long leader between the trap and a fixed point on the shore. Since the leader is 6’ deep with the same size mesh as the box, plus has a float and lead line, it helps funnel fish toward the wings and main box of the trap. The trap is pulled out perpendicular to the shore by boat. The box and wings are fastened open with aluminum spreader bars and secured in place with anchors. The traps are checked by pulling a segment of the trap into or next to the boat and removing fish from the various compartments. Consistency of trap net placement is achieved by using the same anchor point on the shore for setting the trap. Although setting the trap can be impacted by wind and wave action, quality control was maintained by using experienced personnel to set the trap net each month.

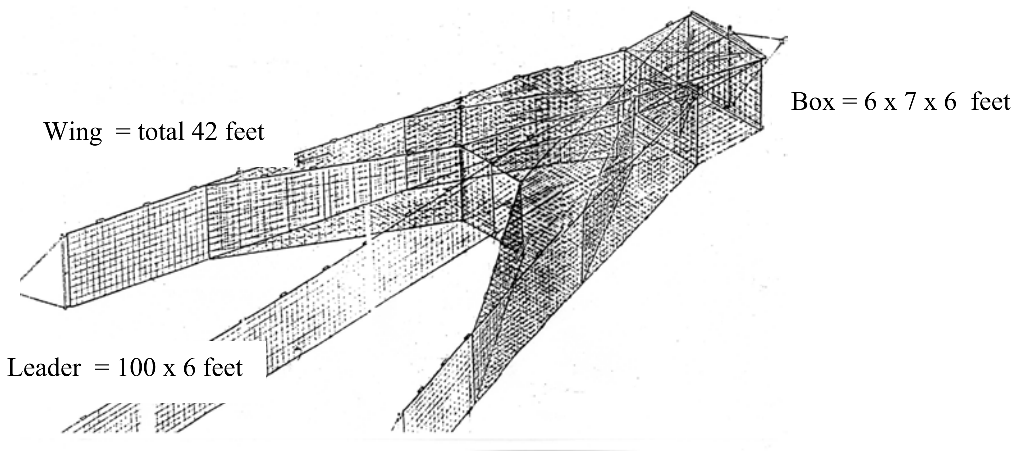

Figure 1. Diagram of trap net used to capture tui chub at Diamond Lake, Oregon.

Rainbow trout fingerlings have been released into Diamond Lake each spring since 1962 (Loomis et al. 1999). A trap net was annually set each October to capture, weigh, measure, and calculate the condition factor and growth rates of the trout. In 1992, a tui chub was captured in the October trap net. From 1992 through 1994, the ODFW continued to set only the October trap net at Noble Fir site (west side of the lake). In 1995, the ODFW began to set a trap net monthly from May through September at the Cabin site on the north side of the lake, and maintained the traditional set at Noble Fir in October. Additional trap net sites have been used periodically for additional sampling (Figure 2). The Cabin site was selected due to the site's gradually sloping bottom, proximity to submerged vegetation (likely to be used by small fish), and the observation of chub. Hydroacoustic sampling in 2002 and 2003 confirmed a high concentration of chub-sized fish along the shoreline of the Cabin site (Eilers and Eilers 2003).

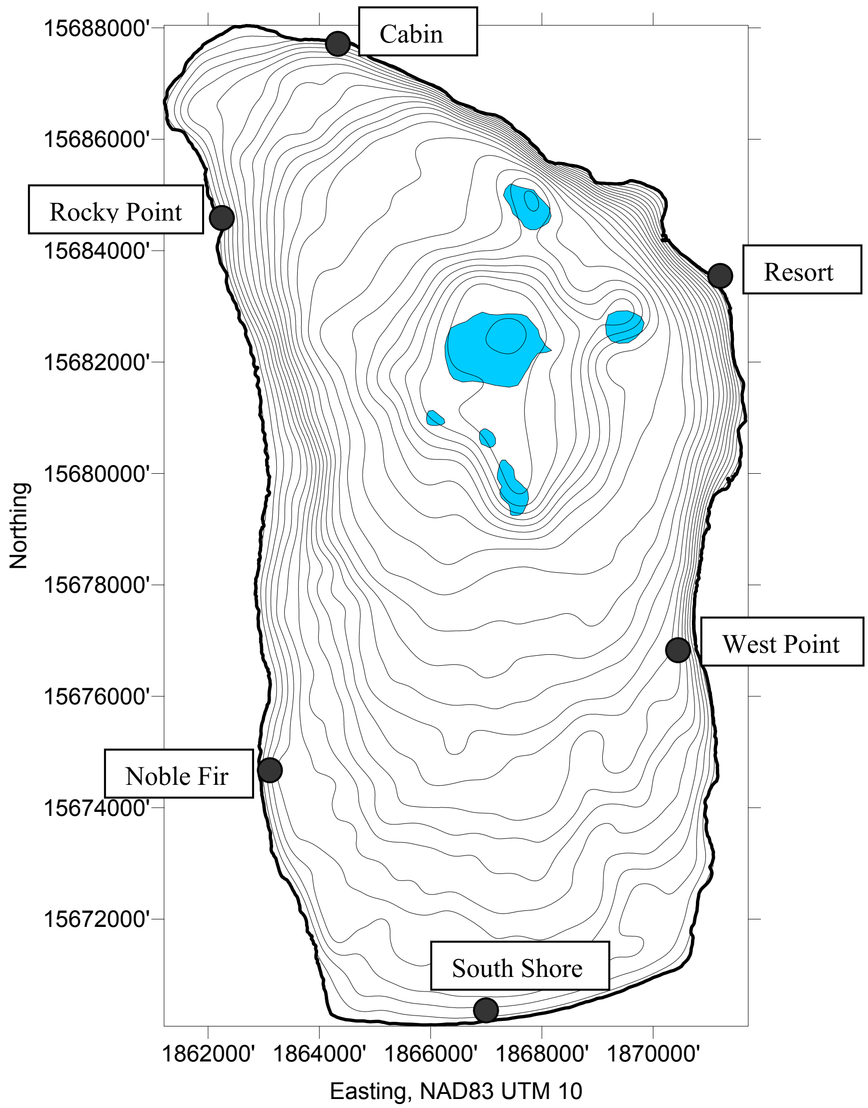

Figure 2. Location of sites used for trap nets at Diamond Lake, Oregon from 1992-2003.

As the total chub caught in trap nets increased from 1 in 1992 to 6,077 in 1995, the ODFW started recording the capture per unit effort (CPUE) of chub. CPUE was calculated by dividing the number of chub captured by the number of trap nets set. Trap net data from all locations were included in calculating the monthly and annual CPUE estimates. The CPUE is a measure of gross relative abundance and is not an actual population estimate. Due to the mesh size of the trap nets, there was a capture bias, which reduced the likelihood of capturing young-of-the year (YOY) chub and chub less than 60mm in length. Due to that bias the CPUE and population estimates based on the trap nets only measure the "catchable" portion of the lake's chub population. A much greater portion of the chub population consists of YOY and chub <60mm that cannot be captured in trap nets.

From 1992 - 2000, ODFW staff counted each chub captured. As the CPUE increased and trap nets began catching >5,000 chub per trap, the number of chub captured was estimated. Estimates of chub captured were calculated by determining the mean number of chub required to fill a 1-gallon bucket (n = 3). Then gallon buckets were filled with chub by hand. Slowly filling the buckets by the handful allowed adequate sorting for other species such as golden shiner (*Notemigonus crysoleucas*) and rainbow fingerlings. Total capture was estimated by multiplying the total number of buckets filled by the mean chub per bucket. If the count ended on a partially filled bucket, individual chub were counted and added to the capture estimated by the full buckets.

Population Estimates

The ODFW has used two methods to estimate the tui chub population in Diamond Lake: Lincoln-Petersen mark-recapture analysis (Seber 1973) and chub : fingerling trout capture ratios (Snedecor and Cochran 1973). In 1999, the ODFW tested the feasibility of using mark-recapture estimates by clipping the tip of the caudal fin on 12,098 of the first 23,646 chub captured (Jackson et al. 1999). It required 8 staff and 240 personnel hours to capture, transport, mark, process, and release the chub. Trap nets set on subsequent days at the same location captured dramatically fewer chub, with only 20% of the initial amount caught on the second day and even less on the third. A total of 184 marked chub were recaptured out of 9,587 chub. It is unknown whether the marked chub died, moved out of the area, or avoided the trap on subsequent days. Due to this dramatic reduction in number of chub captured on subsequent days, the assumption of a "closed" population was violated for a basic mark-recapture population estimate. Using the Noremark (White 1996) Immigration /Emigration model estimate for an open population, the 1999 population estimate was 640,540 tui chub (95% C.I. = 420,080 to 1,051,120). Due to wide confidence intervals and the high personnel commitment required to generate a mark-recapture estimate, the ODFW discontinued the mark-recapture estimates.

The chub population was also estimated by a chub : fingerling trout ratio estimate (Snedecor and Cochran 1973). Each year, after the surface ice melts, rainbow trout fingerlings are released into Diamond Lake. From 1995 – 1999 the ODFW planned that 400,000 fingerlings would be released each year, which was the number used in the ratio estimate. The Fish Liberation Reports (FLR) indicated that the actual releases ranged from 345,000 to 400,050 and varied an averaged of 8.7%. From 2000 to 2003, planned releases were reduced to 50,000 fingerlings/year but actually ranged from 49,982 – 60,000 (an average variance of 5%). This difference between planned and actual release numbers would have caused the chub population to be slightly over estimated during the years when <400,000 trout were released (1996, 1997, 1998, 1999) and under estimated in 2000 when >50,000 fingerlings were released. During 2003, there were 49,982 fingerlings released in Diamond Lake (0.036% less than 50,000).

The rainbow fingerlings weigh 45 - 50 fingerlings/pound when released and are 100 - 115mm in length. This size range is large enough to be captured in the trap nets and is similar in size to most of the chub captured. A major assumption for this estimate is that trout fingerlings disperse throughout the lake and that chub and trout fingerlings are equally catchable in the trap nets. Fingerling trout have been captured at all trap net sites throughout Diamond Lake (ODFW unpublished data), and as stated above fingerlings are the same size as most chub captured, so should be equally catchable. The fingerlings and chub also demonstrate similar distribution within the lake due to their behavior and the physical characteristics of the lake. During May, June and July spawning chub move near the shoreline to lay their eggs on submerged aquatic vegetation. During this time a thermocline develops in the lake, causing the coldest water, which has low oxygen and poor nutrient conditions to occur in the deepest portions of the lake. Chub avoid these depleted conditions and move near shore. Fingerling trout also move into the shoreline portions of the lake as the thermocline develops and seek aquatic vegetation for cover. Hydroacoustic sampling of Diamond Lake supports this movement of fish toward the shoreline and submerged vegetation during summer (Eilers and Gubala 2003; Eilers and Eilers 2003). Opposite lake conditions occur during the fall which corresponds to poorer capture rates of chub and trout fingerlings during September and October (ODFW unpublished data).

Another assumption of the chub : trout ratio estimate is that none of the trout fingerlings die. No significant fingerling trout mortality was observed during any Diamond Lake release since 1995 (ODFW Fish Liberation Reports). Although some transport mortality may occur, it is generally <0.5%. In 2002, transport mortality was 10 out of 49,993 fingerlings or 0.02%. Avian and piscivorous predation is presumed to be minimal. Piscivorous species of trout were introduced recently, but relative to the number of fingerling trout stocked, the chub are a much more readily available prey item. Osprey (*Pandion haliaetus*) and Bald Eagles (*Haliaeetus leucocephalus*) observed during the nesting season are preying on larger food items such as legal-sized trout (ODFW unpublished data). Grebe and gull numbers have increased during recent summers at Diamond Lake, however, this appears to be in response to the increased chub population since fingerling stocking was reduced in 2000.

After meeting the above assumptions, the actual ratio estimate (chub : trout) was calculated by divided by the total number of chub captured by the total number of fingerling trout captured. Since the number of fingerling trout released into the lake was known, the number of chub captured per trout was multiplied by the planned number of fingerlings released. This provided a point estimate of the total number of chub in the lake. The most consistent annual capture data collected by the ODFW was trap net data from the Cabin site (May through September); and the Noble Fir site during October. Thus, only the trap net data from these sets were used to generate the ratio estimate. When multiple traps were set at the Cabin site, only the data from the first trap net was used. Population estimates were generated for June, July, and the total year (starting after the fingerlings were released) from 1995 - 2003.

Length Data

The original intent of using trap nets was to measure trout growth rates; therefore limited length data was collected on chub during the early 1990's. In 1998, total lengths (mm) of 290 chub were recorded during August. In 1999, 1,081 chub were measured during July. In 2000, the ODFW started consistently measuring the lengths of 500 chub from each of two trap nets (Cabin and Noble Fir) set May - October. In 2001, normally only the Cabin site was trapped each month, so measurements were from this site. Variations of this sampling occurred when more than one trap net was set in a month, or when < 500 chub were captured. Only length data from trap nets was used; no length distribution data from tangle nets was used. We attempted to record the actual total length of each chub, however some rounding to the nearest 5mm occurred.

Length data was used to classify chub into 9 size classes. Size classes were based on the age class size data presented by Bird (1975). Since there was considerable overlap in the size range of Bird's (1975) age classes, we based our groupings on the average length of Bird's sample for each age class. We constructed our size classes using the mean of each age class plus ½ of the length distribution between consecutive means. This created exclusive size ranges for each size class.

Bird (1975) noted that tui chub increased in length each year. He noted the largest increase in length occurred during ages 2 and 3 and females grew faster than males until age 7. We did not test for the exact age of tui chub in Diamond Lake. However, based on a the growth pattern described by Bird (1975), we assumed that size class 1 is younger than size class 2; size class 2 is younger than size class 3, etc. With the annual increase in length there is a shift of some chub from one size class into the next each year. Thus size class data was used to create a relative age structure of the chub population to compare for differences in population structure between location, years, and month using Chi square analysis. Due to the low number of fish captured in the larger size classes, size classes 6 – 9 were combined (to reduce the number of empty cells during Chi square analysis). Analysis of variance (ANOVA) was used to test for annual variation in the mean length of chub.

All statistical analyses conducted in this paper were done with SPSS (2003). Data analysis included frequency distributions, Chi square, ANOVA, and regression.

Reproductive Data

In 1999, the ODFW started collecting reproductive information on chub. The abdomen of each chub sampled was opened and examined for the presence of eggs or milt. Chub with eggs were classified as female. Females with eggs which were singled out were classified as ripe whereas females whose eggs were still firm in the egg sac were classified as immature. Females who had a few eggs remaining in the body cavity and no egg sac were classified as spawned-out. Males with gray testes were considered immature while males with testes filled with white milt were classified as ripe. Males with little white milt remaining in the testes were classified as spawned-out. Chub whose sex was not discernible were recorded as unknown. Length data was also collected for all chub internally examined for reproductive status. Thus we were able to classify chub reproductive status by size class, sex, and month of capture. Differences in reproductive status by size class, sex, and date were examined using Chi square analysis.

Since 2000, the ODFW attempted to collect reproductive data on 500 chub/month (May – Oct.). Discrepancies occurred some months when fewer than 500 chub were trapped or in the fall when none of the first 50 – 100 chub internally examined were found in breeding condition. Anabaena algae-blooms prevented trap netting during the following months: August 2001, July 2003, and August 2003. No trap net was set in September 2002 and chub captured in September 2003 were used in a bioassay to test Antimycin A. Thus no length or reproductive data was collected during those 5 months.

Regression Line Analysis: size class estimates, life tables, and fecundity

Based on our size class data, we created an age class distribution for tui chub to use in developing a population model. Since chub <60mm were not adequately sampled by the trap net we used regression to estimate the number of YOY and size class 1 in the population. The number of chub captured during 2003 within each size class 2 – 6 was Log 10 transformed to linerize the data. Because there were fewer size class 2 chub than size class 3, the regression line fit was not strong ($r^2 = 0.661$, $F = 5.84$, $b^0 = 4.3172$, $b^1 = -.6006$, 3df). If size class 2 chub were removed from the data set the regression line fit was ($r^2 = 0.981$), however, the estimate of the number of YOY, size class 1 and size class 2's in the sample was much greater. Thus we used the $r^2 = .661$ regression line to predict the most conservative estimate of the chub population.

The regression equation produced estimates of the YOY and size class 1's in the sample. Using the chub : trout ratio estimate for the total number of catchable chub (23.7 million in 2003), we then calculated a population number for chub in each size class 2 - 6 based on the raw proportion each size class composed. This population estimate of chub per size class was transformed (Log 10) and used to generate another regression line [r^2 = .660, F = 5.83, b^0 = 8.3240, b^1 = -.5990, 3df] that estimated the number of YOY and 1's in the population based on the ratio estimate of catchable chub in 2003. We used the same methods described above to also estimate the number chub per class based on an estimate of 7.6 million catchable chub. The 7.6 million chub estimate represents the mean of the total annual population estimates from 1995 through 2003. The first regression line is the same as above and the adjusted regression line for 7.6 million chub in size class 2 – 6 was [r^2 =0.660, F = 5.83, b^0 =7.8416, b^1 = -.6003, 3df].

Using life table analysis (SPSS 2003), the survival rate per size class was predicted using the numbered captured in size classes 2 – 6, and the estimated YOY and 1's. Although chub larger than size 6 have been previously captured in Diamond Lake, none were captured in 2003, so no survival estimate was generated for chub larger than size class 6.

To estimate the number of eggs produced per female per size class, we used the median length of each Diamond Lake size class as a single point to represent an entire size class. We used Bird's (1975) least square regression to predict the number of eggs for this point. Bird's (1975) regression estimates the number of eggs based on the length of the chub [Eggs = -55898.4 + 12087.1 (chub length in inches)]. For size classes 2 and 3, the median length was smaller than the minimum length (120mm) that produced eggs in Bird's (1975) study. However, Diamond Lake data documented that female chub > 83mm regularly contained ripe eggs. Therefore, we used the minimum number of eggs (669) predicted by Bird's (1975) regression line for the eggs/female in size class 3 and half of that number (335) for the number of eggs produced by size class 2 females.

The techniques used above were also used in 1999 to estimate the size class distribution, survival, and eggs/female of chub based on a 1999 Diamond Lake catchable population estimate of 3 million chub (Jackson et al. 1999).

Population Models

Population models were developed to predict chub population trends based on the 1999 and the 2003 capture data. The 2003 models used two different starting populations based on the chub : trout ratios: the 2003 chub population estimate of 23.7 million and the average population estimate from 1995 to 2003 (7.6 million). All population models were constructed in Excel (Microsoft Corporation, Redmond, WA). The starting population values for number per size class, survival per size class and eggs produced per female were based on the data as described above. The number of females in the population was based on the sex ratio of the 1999 and 2003 capture data. For each version of the 2003 model, the total number of eggs produced by females in each age class was calculated and summed for size classes 2 – 6. The total eggs were divided into the number of YOY as predicted by the regression line analysis. This value was used as the survival rate between the total number of eggs laid and the number of YOY produced. In 1999, it was still unknown that smaller chub in Diamond Lake reproduced, thus the model was based on females not breeding until they reached 124mm (2,120 eggs). In 1999, chub up to size class 8 were captured, thus size class 7 and 8 females produced 44,424 and 48,051 eggs per female respectively. The total eggs produced in 1999 was also summed and divided into the number of YOY estimated by regression analysis to predict the survival rate of the eggs to YOY.

The survival rate of the eggs to YOY and the estimate of survival per size class are constant throughout each model. During each year, the model decreases the starting population by its natural mortality (survival rate). Then for the size classes which reproduce, the post-natural mortality population is multiplied by the percent females in the population and by the number of eggs/female resulting in the total number of eggs produced by each size class. The total number of eggs produced is multiplied by the egg-to-YOY survival rate. This provides the starting YOY population for the following year. The model then transfers the number of surviving chub in each size class to the next larger size class to form the starting population for the next year.

RESULTS AND DISCUSSION

Counts

From 1992 - 2003 a total of 306,645 tui chub were captured in 78 trap nets set by the ODFW. The overall CPUE estimate has steadily increased since the first chub was captured in 1992 (Figure 3). The highest CPUE estimates occurred in 2001 (CPUE =

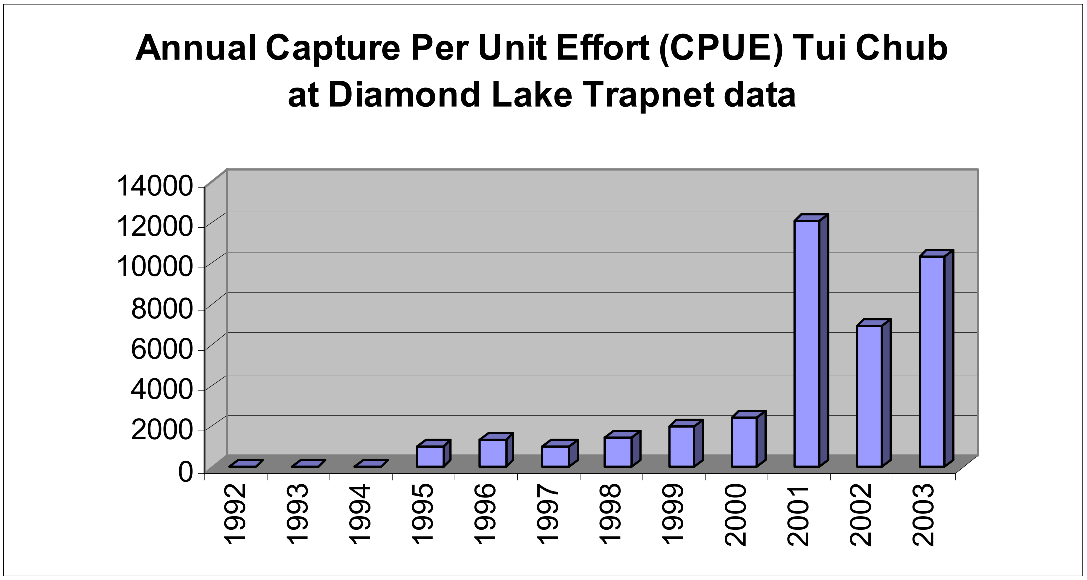

Figure 3. Annual capture per unit effort of tui chub from trap nets set in Diamond Lake 1992- 2003.

12,076) and 2003 (CPUE = 10,319). During these years the ice covering Diamond Lake melted off April 4th and March 24th, respectively, compared to late April in 2000 and 2002 and June 1st in 1999. Consequently the high CPUE values in 2001 and 2003 might have been the result of high over winter survival due to relatively mild winters. Both 2001 and 2003 also had high June CPUE estimates (CPUE = 49,050 and CPUE = 17,768). Although chub congregate in shallow areas during spawning, reproductive activity alone does not explain the increase during these years since the percent of ripe males and females was similar to other years (Figure 4).

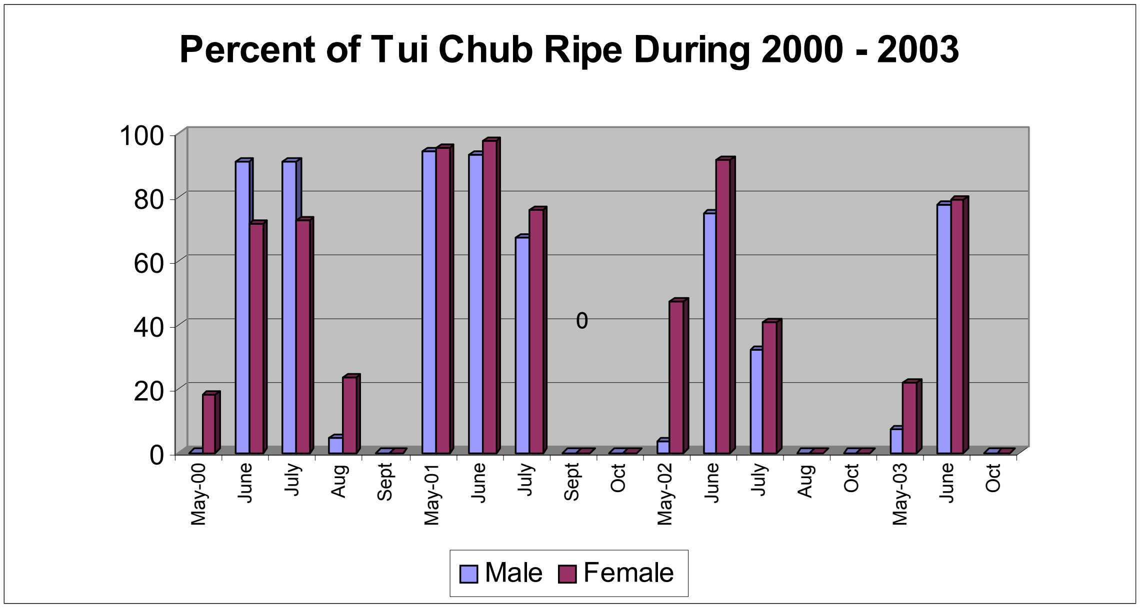

Figure 4. Percent of males and females who were either ripe or spawned out at Diamond Lake, Oregon from 2000 – 2003.

The overall annual CPUE 's could have been influenced by our inability to set the trap net during all months. Anabaena algae blooms prevented trapping during August 2001, July 2003, and August 2003. The CPUE estimates for July have ranged from 4,987 in 2000 to 17,618 in 2002. Likewise the August CPUE estimates ranged from 2,032 to 6,279 during the same period. Trapping during those months would have likely changed the annual CPUE estimate, but it is difficult to predict whether the change would have been positive or negative. The lack of trapping in September 2002 probably had little impact on the annual CPUE estimate since fewer chub are captured during September (Figure 5).

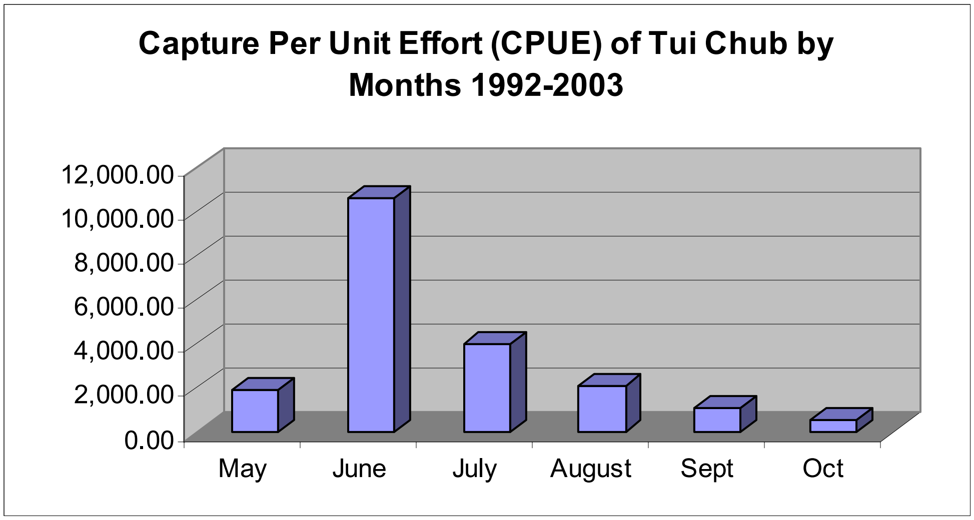

Figure 5. Monthly CPUE of tui chub at Diamond Lake, Oregon 1992-2003.

Population Estimate

From 1995 – 2003 a total of 2,230,000 rainbow trout fingerlings were scheduled for release into Diamond Lake. During that same time period, 194,377 tui chub and 7,549 trout fingerlings were captured in the trap nets used to generate the chub : trout ratios and population estimate for Diamond Lake. Ratio estimates of the catchable chub population have been highly variable (Figure 6). July estimates are much more variable than the June or the total annual population estimates. The June and total annual estimates are similar each year. Both June and the total annual population estimate of chub decreased when the ODFW shifted from releasing 400,000 fingerlings to 50,000 in 2000. This substantiates that the overall increase in the chub population estimate in recent years is not due just to a change in the ratio estimate when the number of fingerling trout released was reduced. In 2002, the annual ratio estimate of 4.9 million chub was less than the estimate of >10 million chub based on hydroacoustic sampling (Eilers and Gubala 2003). We attempted to use regression analysis of the total annual population estimates from 1995 – 2003 to predict future chub populations. However, the high variability of the data precluded using the regression line ($r^2 = 0.040$). Therefore the most current data (2003) was used for the population models discussed below. The total annual estimate of 23,760,000 represents the lowest number of catchable chub estimated in Diamond Lake during 2003 (June data estimated 29 million chub and there was no July trap). From 1995 to 2003, the mean of the total annual population estimates was 7,644,000 chub. Thus, as a more conservative version of the model, we also developed a second model based on a starting population of

7,644,000 catchable chub.

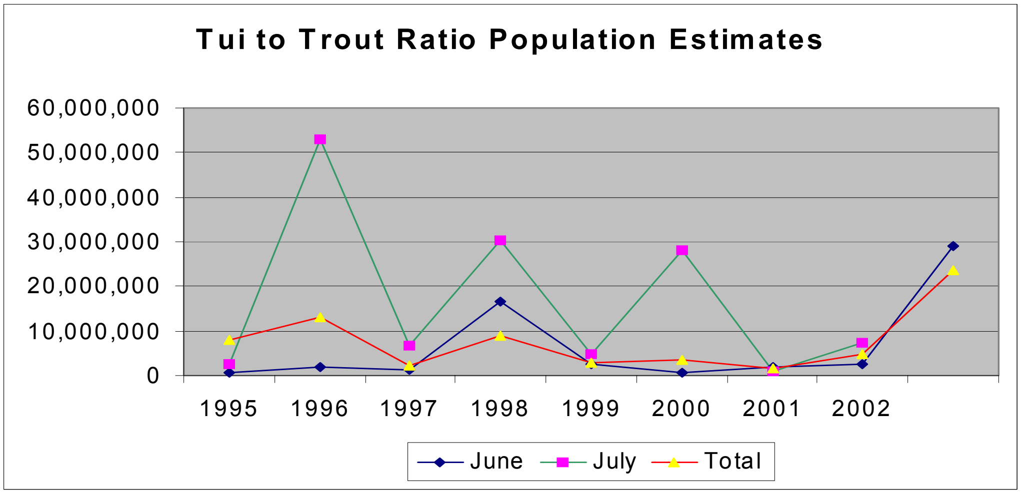

Figure 6. Tui chub population estimates for Diamond Lake, Oregon based on chub : trout capture ratios, 1995 - 2003.

In comparison, if the actual FLR fingerling trout release numbers were used for the chub : trout ratio estimate, a total of 66,010,613 chub would have been predicted from 1995 – 2003 versus the total annual estimate used above (68,802,000 chub). This represents a 4% difference in the ratio estimates between the actual fingerling trout release numbers and the planned releases.

Length Data

Length data was gathered on 14,084 chub captured in 36 different trap nets set in Diamond Lake from 1998 – 2003. Chub length ranged from 10mm - 240mm (Figure 7). Length data was grouped into size classes (Table 1) to compare for significant differences in the population's size structure between location and years. There was a significant difference (X^2 = 793.062, P = 0.000, 25df) in size between the six sites (Figure 2) used to capture chub. Of the total length data gathered at each site, the Resort (n = 226) had the largest percent of size class 1 and 2 chub (14.2 and 55.8% respectively) followed by Rocky Point (n = 200) which had 8.5% and 50.5% size 1 and size 2 chub. Size class 3 comprised the largest percent of the total sample (64.2%) with the West Point (n = 100), Cabin (n = 8,068), and the South Shore (n = 399) being composed of 79%, 70.4% and 65.4% size class 3 chub, respectively. West Point had the largest percent of size class 4 and 5 chub (16% and 2%). Noble Fir (n = 5091) had 0.6% chub in size class 6 – 9, while the other sites had even less.

Table 1. Size classes of tui chub captured in Diamond Lake, Oregon, 1998 – 2003.

Size Class	Range (mm)
1	32-59mm
2	60-94mm
3	95-131mm
4	132-161mm
5	162-185mm
6*	186-204mm
7*	205-215mm
8*	216-300mm
9*	>300

*Combined into size 6 for Chi square analysis.

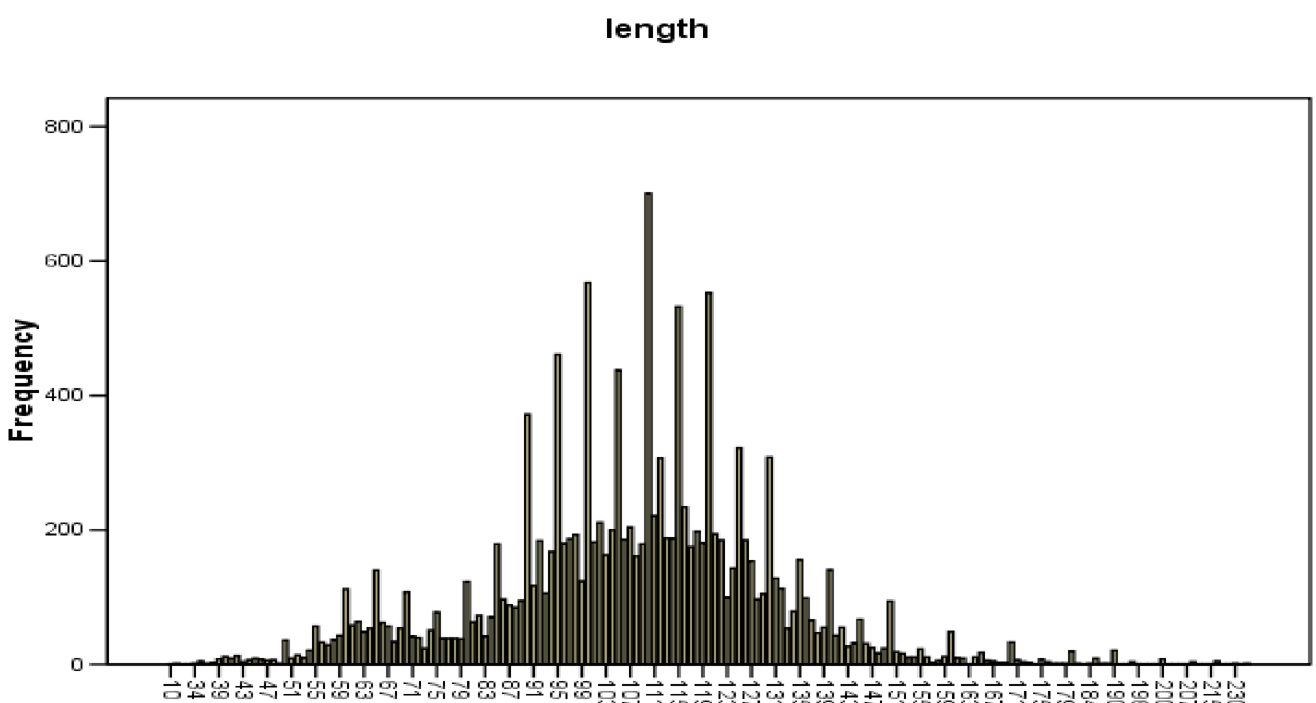

Figure 7. Length distribution of 14,084 tui chub captured in trap nets at Diamond Lake, Oregon, 1998 – 2003.

The Cabin site, which provided monthly data, documented that most size class 1 chub were captured in August and September. This would be expected since YOY chub born the previous summer would have grown during the summer to the size class 1 length. Size class 1 chub are less than 60mm and under represented in our samples; only 387 size 1 chub were captured from 1998 - 2003.

There was a significant difference in size class distribution between years (X^2 = 2798.650, P = 0.000, 25df). The widest size class distribution occurred in 1998, despite having the smallest sample size (n = 290). The size class distribution then became increasingly truncated through 2001. In August 1998, chub in size classes 6, 7, and 8 comprised 9%, 1.4%, and 3.8% respectively of the sample. In 1999 (n = 1,080), the same size classes only comprised 0.6%, 0.2% and 0.1% of the chub measured. The change in size distribution is illustrated in Figure 8. No size class 8 chub have been captured in trap nets since 1999 and no chub in size class 7 have been captured since 2000. This corresponds to the same time when ODFW staff noted extremely poor growth rates in both fingerling and legal-size trout (~ 8 inches in length) released into Diamond Lake (ODFW, unpublished data). Salinas (2000) supports this in his Diamond Lake limnological study (1994 – 2000) which noted that chub changed the survival of fingerling trout by out-competing them for zooplankton and benthos food resources. Eilers et al. (2001) noted that larger taxa of zooplankton have decreased during the last decade in Diamond Lake based on core samples. Bird (1975) noted an overlap in diets between trout and chub. Thus it is possible that the larger size classes of chub are becoming stressed and exhibiting lower survival due to a reduction in food resources. Although the number of large chub has decreased since 1999, the total number of chub has increased based on the CPUE and chub : trout ratio estimates.

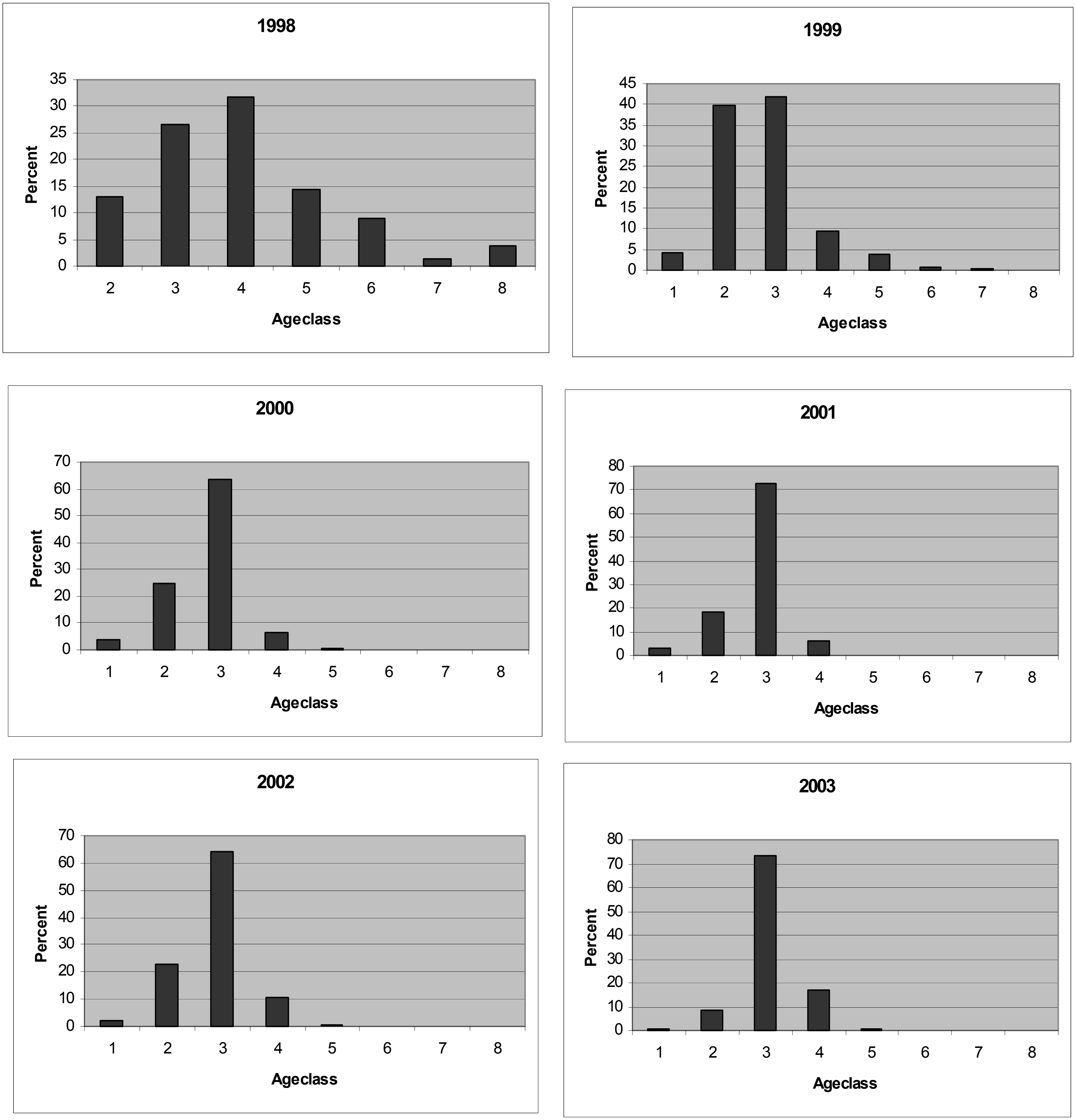

Figure 8. Age class distribution of tui chub at Diamond Lake, Oregon from 1998-2003.

There was a significant difference in the mean length of captured chub between years (P = 0.000, F = 259.919). In 1998, chub length averaged 141.9 mm whereas from 1999 - 2002 the annual mean length ranged between 101.2 mm and 107.5 mm. The mean length of chub in 2003 was 116.4 mm. In 2003, size classes 4 and 5 which had decreased to a low of 6.2% and 0.2% of the annual sample in 2001 (n = 1,966), increased to 17.1% and 0.7% of the sample (n = 2,290) in 2003. This increase in percent of size classes 4 and 5 could be due to more size class 3 chub becoming size class 4, or it could reflect an actual increase in chub growth rates or survival.

In a normal age class distribution for a population, you would expect more fish in younger age classes than the next older age class. Chub in Diamond Lake had a somewhat normal size class distribution in 1998 and 1999 although size class 2 appeared to be slightly under represented. From 1998 to 2000, size class 2 chub averaged 27% of the annual length samples. From 2001 to 2003, this dropped to an average of 17% of the annual length samples. This could be a result of a slower growth rate, which could explain the large percent of chub in size class 3, and the corresponding decrease in the adjacent size class 2 and 4. However, Eilers and Eilers (2003) documented a normal size class distribution of fish in Diamond Lake using hydroacoustic technology. This suggests that size class 2 chub may be presently under-sampled in the trap nets.

From 1998 – 2003 the largest percentage of size class 2 chub were captured during the months of July, August, and September, 18.3%, 31.7% and 25.2% respectively. Due to lake closures and the bioassay, no length data was collected in August 2001, September 2002, and July - September 2003. The inability to capture and measure chub during these months might explain the reduced percent of size class 2 chub. In 2000 the ODFW also started using a new trap net at Diamond Lake. Although the new trap net was ordered to the same specifications, measurements of the mesh size show that the old net had a smaller mesh (6.09 mm x 5.05 mm) than the new net (6.23 mm x 9.25 mm). Thus the change in mesh size, or any difference in how the trap floated could have reduced the catchability of size class 2 chub. The change in mesh size should not have altered the catchability of fingerling trout since they are in the size class 3-length range and over 64% of the chub captured (n = 9,036) were size class 3. Both the old and new nets were used each month in 2000. The new net has been used at each set since 2000 with the exception of two sets in August 2002. If there were a reduced catchability of size class 2 chub with the new trap net, the capture bias would cause the chub : trout ratio estimates of the chub population to be under estimated.

Reproductive Data

Reproductive data was collected on 6,516 chub from 1999 – 2003. Chi square analysis showed a significant difference in the sex ratio of chub in Diamond Lake between years ($X^2 = 32.192$, $P = 0.000$, 4df). In 1999, 43.2% of the chub were females; this dropped to 30.4% females in 2003. Spawning activity varies, but tends to be highest during May, June, and July. Including ripe and spawned out females (96.3% and 1.3%), spawning has been documented in 97.6% of the females captured in a single month (Figure 4). Likewise up to 94.3% of the males captured in one month have been reproductively active. Female chub as small as 67mm have been documented as ripe, but ripeness becomes more frequent in female chub >83mm. From 1999 – 2003, 42.9% of the size class 2 females were documented in spawning condition during June and July. Our trapping method does not allow for following individual chub over time. Thus, since eggs had to be present for a chub to be classified as a female, it is likely that many female chub which were immature in May, June or July would have subsequently matured and spawned a few weeks later. A few chub spawn in August, however, no ripe males or females were documented during September or October.

Population Models

Model of 23.7 Million Chub, 2003

To develop a complete life table of chub in Diamond Lake we used regression to estimate the number of size class 1 and YOY in the population. Since there was a significant difference in the size class distribution of chub between years, we used the most current capture data (2003). Likewise there was a significant difference between annual sex ratios between years, so we used the 2003 data to estimate the sex ratio. We also used the annual 2003 chub : trout ratio estimate (23,760,000) as our catchable chub population estimate. This was the most conservative chub population estimate for 2003. Since size class data were significantly different between locations and months, we pooled all of the size class data for 2003. This provided the best total distribution of size classes to reflect the chub population in Diamond Lake during 2003.

We used the 2003 capture data for each size class 2 – 6 to generate the regression line (Table 2). Capture data was transformed (log 10) and used to develop the equation [Y = -.6006 (age) + 4.3172]. The log values for size class 1, and YOY were calculated by replacing age in the equation, 1 and 0 respectively. These estimates were then converted (anti-log) to actual estimates of size class 1 and YOY that should have been caught. Then, since the catchable portion of the population (size classes 2 – 6) was known, the total population estimate of 23,760,000 was proportionally placed into the appropriate size class based on the original proportion each size class composed of the capture (Table 2). These population values for size classes 2 - 6 were once again used in a regression line and the equation [Y = -.5990(age) + 8.3240] was used to estimate that there were 210,862,815 YOY and 53,088,444 size class 1 chub in Diamond Lake based on a population estimate of 23.7 million catchable chub. Totaling the YOY, size class 1 and all of the catchable chub, there was an estimated 287,711,021 chub in Diamond Lake in 2003 (Table 2). Of those chub, only 8% were catchable, whereas over 73% were the small translucent YOY that cannot be captured using standard trapping methods. Life table analysis was used to predict the annual survival rate per size class based on the original capture data and the estimated population of size class 1.

Table 2. Size class distribution of tui chub in Diamond Lake, Oregon during 2003 based on a population estimate of 23,760,000 catchable chub.

Size Class	No. chub captured	% of chub captured	No. based on 23 mill.	Survival Rate	Median length In mm	Eggs Per Female	Total eggs produced in 2003
YOY	20,759*		210,862,815*	.01	NA		
1	5,207*		53,088,444*	0.265	NA		
2	190	8.336	1,980,634	0.3044	77**	335	199,053,717
3	1,681	73.760	17,525,376	0.9166	113**	669	3,517,342,963
4	391	17.157	4,076,503	0.1953	147	13,397	16,383,873,207
5	15	0.658	156,341	0.0417	173	25,653	1,203,184,702
6	2	0.088	20,909	0.1176	195	36,024	225,967,745
7	0	0	0	0	210	43,095	
Total	28,245	99.999	287,711,022				21,529,422,334

*Numbers extrapolated from log 10 transformation.
**Used minimum eggs allowed by Bird (1975) for size 3, and ½ of that for size 2.

To complete the data necessary for the population model we used Bird's (1975) least square regression to estimate the number of eggs produced per female based on the median of the length range of each size class (Table 2). For size classes 3 and 2 we used the minimum number of eggs/female predicted by Bird (1975) for size class 3 and half of that number for size class 2. It should be noted however, that although chub at the minimum length (120mm) are predicted to produce only 669 eggs, Bird's (1975) regression line is so steep that chub at 125mm produce 3,026 eggs while chub at 131mm (the end of size class 3) produce 5,855 eggs per female. Thus, potentially we could be under estimating the number of eggs produced per female in size class 3.

Only 30% of the chub captured in 2003 were female. Thus to estimate the number of eggs laid, we multiplied the percentage of females in the population (30%) by the total number of chub in each size class from 2 – 6 to calculate the number of females. We then multiplied the number of females/size class by the number eggs per female/size class to estimate the total number of eggs laid by chub in 2003 (Table 2). This estimated that >21.5 billion eggs were laid by chub in Diamond Lake in 2003. Since over 97% of the female chub have been documented spawning in a single month, our model assumed that 100% of the females in size classes 2 – 6 would produce eggs. We divided the total number of eggs produced (21.5 billion) by the YOY estimated at Diamond Lake in 2003 (210.8 million) to estimate the egg to YOY survival (1%).

This 1% survival rate estimate was higher than the 0.1% egg to YOY survival predicted by Bird (1975). However, Bird's data was based on only 4 female tui chub. He noted that the egg to YOY mortality in his study might have been high because the tui chub were forced to spawn on rocks instead of vegetation. This could have made the eggs more vulnerable to an unknown fungus which killed the eggs (Bird 1975). Bird (1975) was able to document some potential natural mortality caused by the fungus on Blue chub (*Gila coerulea)* eggs, but he was unable to document any mortality in tui chub since no natural tui chub spawning areas were found. Bird (1975) also failed to discuss whether or not the upwelling water system he used for incubation might have also contributed to a higher than normal egg mortality in a species which spawns in relatively calm lake water. The tui chub eggs might have died due to water turbulence or by becoming more easily dislodged from the rocks than what would have occurred if the eggs had been attached to vegetation. Thus, since the egg to YOY survival predicted by Bird (1975) was likely low, we used the survival rate as predicted by the data collected at Diamond Lake.

The model operates by reducing the annual starting population (after year one), of each size class by the natural mortality (survival rate) to produce the new population estimate for the year. To calculate reproduction, the surviving females in each size class are multiplied by the eggs/female. Total egg production was obtained by adding all size class production, then multiplying by 1% to predict the YOY for the next year. The survivors from each size class move to the next larger size class the following year as the starting population. Model calculations were repeated for 20 consecutive years (2003 – 2022). Survival rates, the sex ratio and eggs/female remain constant throughout the duration of the model.

In the no action model, no artificial mortality was added to model to reduce the chub population. Thus the model estimates the natural population trend. The no action model shows a slowly declining population which decreases from 23.7 million to 17.8 million catchable chub in 2022 (Figure 9). The annual reproductive potential also declines from 21.5 billion eggs to 10 billion eggs by 2022. This is caused by the low percentage of females used the population model.

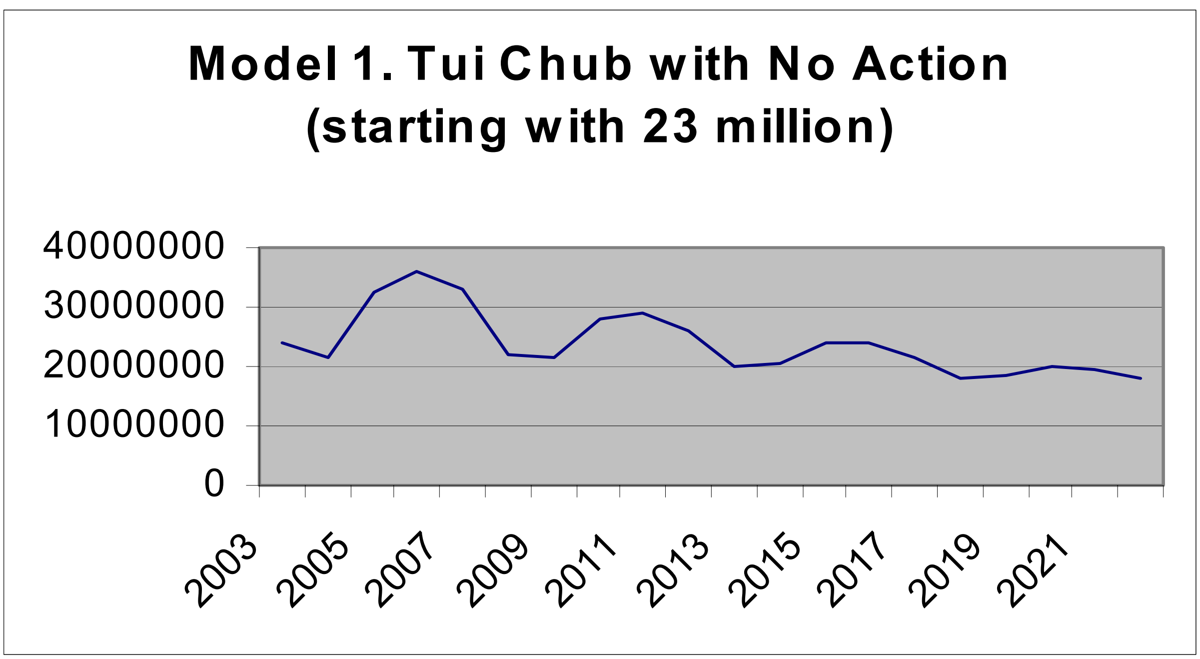

Figure 9. Tui chub model for Diamond Lake, Oregon, based on 2003 capture data and a starting population of 23 million chub.

Model of 7.6 Million Chub, 2003

The above process was repeated for a model based on a catchable population of 7.6 million chub. This value represented the mean annual population estimate of chub in Diamond Lake from 1995 to 2003. Using the methods described previously, a starting population of 94 million chub and 6.9 billion eggs was predicted (Table 3). After 20 years of model calculations, there were still 5.7 million catchable chub capable of producing 3.2 million eggs (Appendix 2). Again, the chub population slowly declines but never goes extinct in 20 years (Figure 10) and retains a high reproductive potential.

Table 3. Size class distribution of tui chub in Diamond Lake, Oregon during 2003 based on a population estimate of 7.6 catchable million chub.

Size Class	No. chub captured	% of chub captured	No. based on 7.6 mill.	Survival Rate	Median In mm	Eggs Per Female	Total eggs produced in 2003
YOY	20,759*		69,438,447*	.01	NA		
1	5,207*		17,430,105*	0.265	NA		
2	190	8.336	637,260	0.3044	77**	335	64,044,630
3	1,681	73.760	5,638,706	0.9166	113**	669	1,131,688,294
4	391	17.157	1,311,595	0.1953	147	13,397	5,271,431,465
5	15	0.658	50,302	0.0417	173	25,653	387,119,162
6	2	0.088	6,727	0.1176	195	36,024	72,700,034
7	0	0	0	0	210	43,095	
Total	28,245	99.999	94,513,142				6,926,983,585

*Numbers extrapolated by Log 10 transformation.
**Used minimum eggs allowed by Bird (1975) for size 3 and ½ of that for size 2

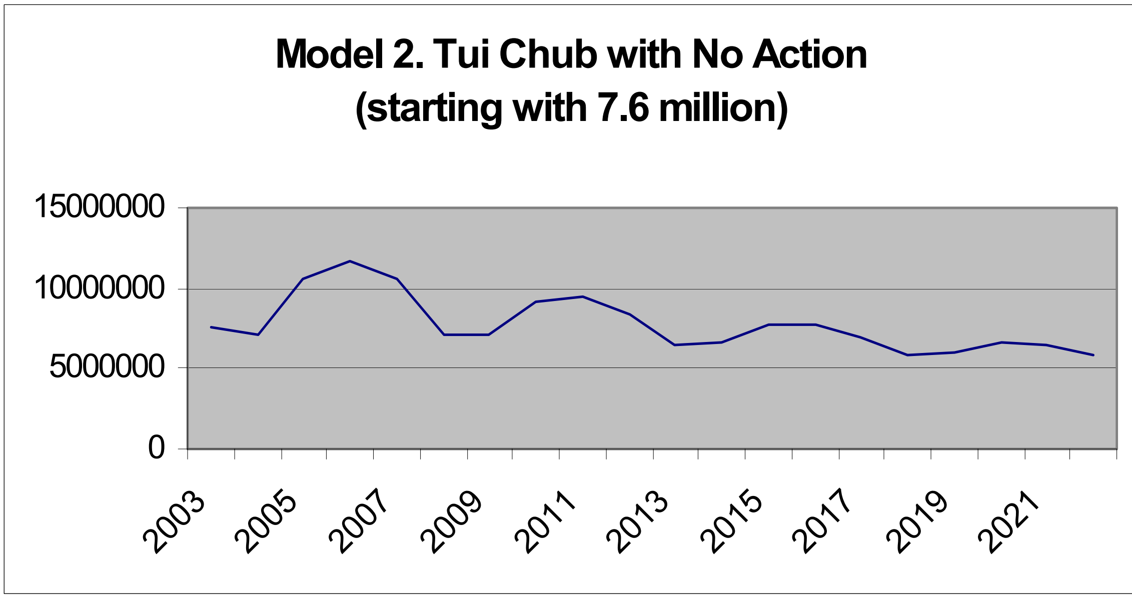

Figure 10. No action model of the tui chub population in Diamond Lake, Oregon from 2003 – 2022 with a starting population of 7.6 million catchable chub.

Model of 3 Million Chub, 1999

The methods used in this paper to develop a chub population model were first tested in 1999 (Jackson et al. 1999). At that time it was unknown that size class 2 and small size class 3 chub reproduced, thus only chub 124mm or larger were used to calculate the reproductive potential of chub. In 1999, chub up through size class 8 were still present in Diamond Lake and females composed 43% of the population, thus these parameter values were used in the model. Using the methods previously described, the egg-to-YOY survival calculated in 1999 was 0.5% which was less than the 1% survival predicted in 2003. Capture data in 1999 reflected a more normal size class distribution and survival per size class was generally higher than the 2003 estimates. Using a starting population of 3 million catchable chub and no action to reduce the population, the 1999 model predicted a slowly increasing chub population, which grew to over 4 million (Figure 11).

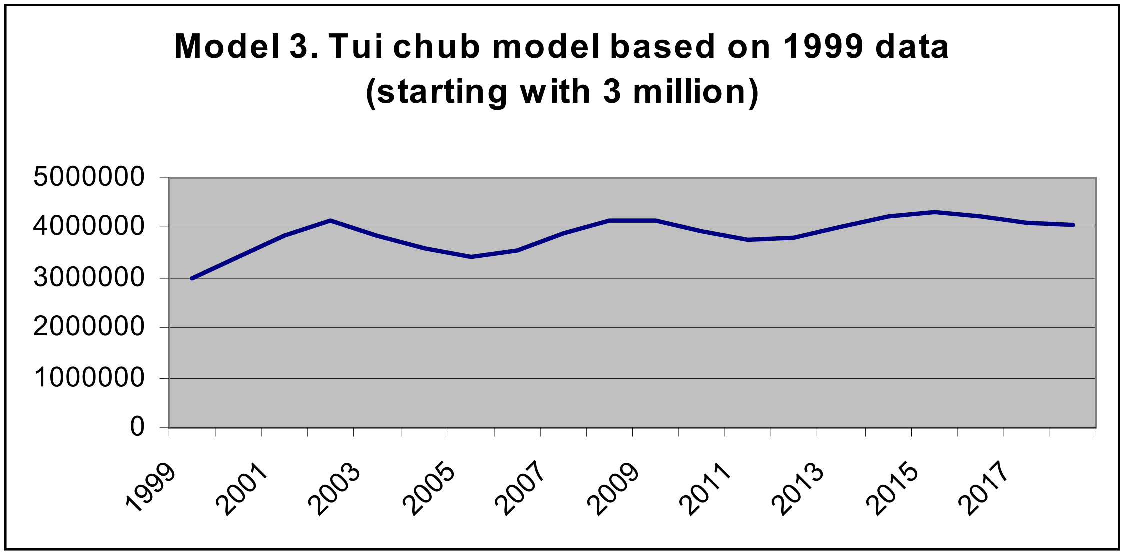

Figure 11. Tui chub model based on 1999 capture data and a starting population of 3 million chub for Diamond Lake, Oregon.

In 1999 based on the increasing CPUE, wide size class distribution, and sex ratio of chub, the ODFW had predicted an increase in Diamond Lake's chub population. The model supported this prediction. The 1999 model predicted a population of 3.4 million, 3.8 million and 4.1 million chub in 2000, 2001, and 2002, respectively. During the same years, the chub : trout ratio estimate predicted 3.4 million, 1.7 million, and 4.9 million chub, respectively. The 1999 model greatly under estimated the 2003 chub population ratio estimate of 23.7 million. However, as noted above small chub in the model were not "allowed" to produce eggs and the egg-to-YOY survival was half of the current estimate. The model also does not have any biofeedback mechanisms to account for changes in survival. If, for example, the mild winters of 2000 – 2001 and 2002 – 2003 did result in a higher over-winter survival of chub, the model could not have predicted the increase in the number chub since survival rates are kept constant. Any increase in chub survival would have dramatically increased the number of eggs produced. Thus an increase in the number of chub surviving and producing in 2001 would have resulted in a greater number of catchable-sized chub in 2003. This combined with the mild winter of 2002 – 2003 could have resulted in the dramatic increase of chub documented in the 2003 CPUE and ratio estimates.

CONCLUSIONS

Based on a capture of over 306,000 chub, the annual CPUE of chub in Diamond Lake has steadily increased since 1992. Population estimates based on chub : trout ratio estimates are highly variable but indicate a current long-term average population of 7.6 million (1995- 2003) to 23.7 million (2003 only) catchable chub. An independent hydroacoustic study estimated a population of 10 million chub in the open water portion of the lake in 2002 (Eilers and Gubala 2003). However, Eilers and Gubala (2003) noted that this estimate might only represent a small percentage of the tui chub in Diamond Lake due to the chub's preference for submerged vegetation.

Although the chub population increased in Diamond Lake since 1992, the chub presently appear to be demonstrating signs of density-dependant stress. The size class distribution of chub has become skewed and no chub in size classes 7 and 8 have been captured in recent years. Like trout of the same size, the larger size classes of chub may have lower survival due to a reduction of food resources. The percent of female chub in the population has also declined from 43% to 30%, and may indicate a physiologically stressed population.

Reproductive activity is highest during May, June, and July and as many as 97.6% of the females and 94.3% of the males have been documented in breeding condition during a single month during this time. Few chub spawn in August and no spawning has been documented in September or October. Although our capture methods precluded following individual chub over time, the data suggests that tui chub in Diamond Lake probably only spawn once per year. However as Bird (1975) noted, with optimal conditions, there is a possibility that they could spawn twice. Optimal conditions for spawning would likely occur at Diamond Lake only during years with an early ice melt-off. Thus one could speculate that the increase in CPUE during 2001 and 2003 could be a result of some chub returning to the shallows a second time to spawn.

The two 2003 models described in this report were based on the most conservative parameter values possible. The lowest population estimate for 2003 was used as the catchable chub population of the first model and even more conservative value of 7.6 million chub was used for the second model. The regression analysis used size class 2 chub capture data, even though this would lower the population estimate of size class 1 and the YOY. The 2003 models also used a sex ratio of 30% female and did not allow survival past size class 6. Using the current data, the 2003 models showed a slowly declining (physiologically stressed) tui chub population in Diamond Lake.

Conversely, the model built on the 1999 capture data when the chub population was still believed to be healthy, demonstrated an increasing population. This suggests that the ODFW capture data are relevant in building predictive models for both healthy and stressed chub populations. The 1999 model predicted nearly the same number of chub as did the chub : trout ratio estimates in 2000 and 2002. However, none of the models currently have biofeedback mechanisms that allow changes in factors such as survival, growth rates, or sex ratios. With the high egg-laying potential of tui chub, any increase in chub survival could result in a large increase in the number of chub produced. However, trap nets could not document an increase in chub production until two to three years later when the YOY cohort becomes large enough to be captured. Approximately 92% of the chub population is composed of YOY or size class 1 chub that are too small to be captured by trap nets. This might explain the highly variable annual catchable chub population estimates.

The data presented in this paper provides a basic understanding of tui chub in Diamond Lake. The data demonstrates that the current population may be experiencing some natural density-dependant stress. Using the most conservative parameter values possible, the 2003 models still predict a large number of chub surviving in Diamond Lake for the next 20 years. Due to the chub's high reproductive potential, it would be difficult to control the chub population merely by reducing the number of chub. A reduction in chub numbers would likely result in additional in food resources which could result in higher size class survival rates, more chub surviving to larger sizes, and more females in the population such as observed in 1999. This could allow the chub population to quickly rebound from any temporary reduction.

ACKNOWLEDGMENTS

Our thanks to the dedication of the ODFW Umpqua District fish staff for handling thousands of tui chub during the last six years, in addition to all of their other duties. We also appreciate the support of Rock Creek Hatchery, Oregon State Police, and Diamond Lake Resort. Team Chub includes: J. Brick, S. Callaway, B. Cannaday, F. Carr, D. Chambers, J. Collins, M. Collins, S. Denney, S. Dunnavant, N. Duncan, L. Freeman, D. Frerichs, M. Grover, J. Haire, D. Harris, B. Hart, D. Jenkins, S. Koch, J. Kurcher, J. Lee, J. Lowry, T. Loynes, J. Mattos, D. Meyer, S. Moyers, J. Muck, J. Myhre, B. Pentaluma, B. Peters, J. Potter, J. Raasch, R. Rockholt, J. Schmitz, D. Sharp, C. Sheely, S. Sjogren, G. Valenzuela, R. Webb, T. Wilgus, and M. Williams.

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